Application of cautions, warnings and triggers to benthos for the GVRD marine WWTP outfalls

Brenda Burd (Ecostat Research Ltd), Albert van Roodselaar and Stanley Bertold (Greater Vancouver Regional District)

Keywords: LWMP, Triggers, Warnings, biota, sediments, geochemistry

The Trigger Process

The Greater Vancouver Regional District (GVRD) has committed to the principle of managing liquid waste in a sustainable and cost effective manner that protects and enhances the receiving environment. This commitment is detailed in the District's Liquid Waste Management Plan (LWMP). Upon approval of the LWMP, the Minister of Water, Lands and Air Protection (WLAP) required that the GVRD "Develop the environmental 'triggers' used in the monitoring process by January 31, 2004, recognizing that the environmental monitoring process in the LWMP is based on discharge indicator trend analysis such that action will be implemented before Water Quality Objectives or other criteria are met or exceeded". A key component of the LWMP involves monitoring, assessing and forecasting to evaluate effects of GVRD's liquid waste discharges. Environmental monitoring will determine, through application of the cautions, warnings and trigger process, if and where discharges are contributing to environmental risk. If the results of the monitoring indicate effects in the receiving environment, the GVRD will respond via the process outlined in the LWMP. This document contains a condensed version of an overall Triggers framework based on receiving environment effects. For more information relating to the process or the complete document (GVRD 2004), contact:

Albert van Roodselaar, Ph.D., P.Eng.,
Greater Vancouver Regional District
Policy and Planning Department
4330 Kingsway, Burnaby, British Columbia
Canada V5H 4G8
Tel: (604) 432-6375: Fax: (604) 436-6970

There are five wastewater treatment plants (WWTP) in the GVRD. The Iona Island and Lions Gate WWTPs provide primary treatment, and discharge to the marine environments of Georgia Strait and Outer Burrard Inlet, respectively.

The cautions, warnings and triggers approach is applied to three compartments of the aquatic environment, including the water column, sediment quality, and biota (including benthic biota higher trophic levels - see GVRD 2004). In this paper, the application of the trigger process to benthic biota is discussed. Only the marine outfalls are considered, since an ongoing benthic biological monitoring program is not in place for the other discharges, with particular emphasis on the Iona wastewater treatment plant outfall.

The approach to defining cautions, warnings and triggers in the benthos involves defining ecologically and statistically relevant departures from background or existing biotic conditions, since there are no widely accepted biotic guidelines for benthos (see Burd 2002). Biotic indicators integrate the long-term, chronic and acute effects of effluent exposure from wastewater discharges. The marine benthos encompasses a range of organism sizes and trophic levels which are the most direct targets for the settlement of particulate materials from municipal liquid waste discharges. The infaunal benthos tend to be numerous and diverse in marine sediments, and thus amenable to statistical analyses of distributional patterns. Most species have a life span of 1-5 years, and spawn annually, making changes in distribution patterns of the fauna interpretable in an annual monitoring program.

GVRD (2004) describes issues and questions which had to be addressed during the exposure, warning or trigger indicators selection process, as well as preliminary tasks which were required to develop benthic cautions, warnings and triggers for the Iona and Lions Gate receiving environments. Tasks included a review of indicators and triggers from other jurisdictions (Burd 2002) and an ecological significance assessment of the monitoring data for Iona from 2000 to 2003 (Burd 2003). Because the IONA monitoring program is the more long-term and advanced of the two, with clear-cut sediment deposition patterns related to the outfall, the development of cautions, warnings and triggers was based primarily on this data.

Exposure Indicators

Exposure indicators provide a context of the spatial extent and magnitude of receiving environment exposure to the discharges. The selection of indicators depends on a number of factors including reference ranges, overall consistency, potential for influence from confounding factors, ecological relevance to ecosystem health and overall recognition by other jurisdictions. Cautions, warnings and triggers must therefore be based on selected exposure indicators.

Cautions

Most regulatory agencies define ecosystem health as some proportional deviation from "normal" or "reference" conditions (see Burd 2002). Therefore, in order to set standards, the temporal and spatial scale of variability expected in background "present-day" conditions must also be determined.

Cautions occur when spatial and/or temporal changes have occurred in ambient or reference conditions outside a pre-determined margin set by sampling methodology. Cautions provide a means of continuously assessing the performance of reference levels for indicators, for recognizing unexpected (natural and anthropogenic) influences external to the discharge, changes in methodology for monitoring programs or long-term natural environmental or biological cycles. The ongoing Ambient Monitoring Programs in the Strait of Georgia and the Fraser River provide further validation of reference ranges.

Warnings

Warnings indicate change in substance or biota levels of potential ecological concern relative to the current condition of the given receiving environment, which can reasonably be attributed to the discharge in question. Exceedance of a warning level initiates intensified sampling and monitoring to confirm cause, predict progression towards trigger status and assess the potential need for actions to slow, reverse or stop the observed trend.

Triggers

Triggers are based on negative changes beyond warning levels in the receiving environment, ultimately showing a trend towards environmental degradation in the future and therefore harboring pressing ecological imperative. Trigger levels will ultimately prompt some mitigating action, which may have far-reaching societal, environmental and economic implications. The ultimate goal is to never reach a trigger limit. Nnegative trends are intended to be reversed before triggers are reached.

Iona Island WWTP

The Iona outfall discharges into the eastern margin of the Strait of Georgia off Sturgeon Bank (Fig. 1). The monitoring program for Iona WWTP receiving environment effects was recently revised based on a 10-year review of the historical program (2WE Consulting 1999). A key revision was the adoption of a revised sampling gradient. The best evidence of the distribution of Iona discharge effects on sediments prior to 2000 was the study of sediment silver by Gordon (1997). According to this study, sediment effects might be expected along the 90 m depth contour in a gradient to the north, and less so to the south of the outfall. Results of the Hodgins and Hodgins (2000) report on modeled sediment deposition of total suspended solids suggest that initial deposition is maximal upslope of the 90 m contour. Therefore, significant down-slope sediment transport is occurring over time. A compromise to identify the maximum exposure zone resulted in choosing the 80 m depth contour for sampling (see Fig. 1). The cross-transect survey undertaken in 2003 (see EVS 2004) confirmed that the 80m contour is the zone of maximum deposition. The revised program has been completed annually for 2000 to 2004 (Bailey et al. 2003, McPherson et al. 2001, 2002, 2004, 2005). However, the triggers framework is based on monitoring data from 2001 to 2003. Data from 2000 was instrumental in determining types and extent of effects from the outfall, but a considerable change in field and laboratory protocols between 2000 and 2001 made the 2000 data comparable to future sampling data in a qualitative way only.

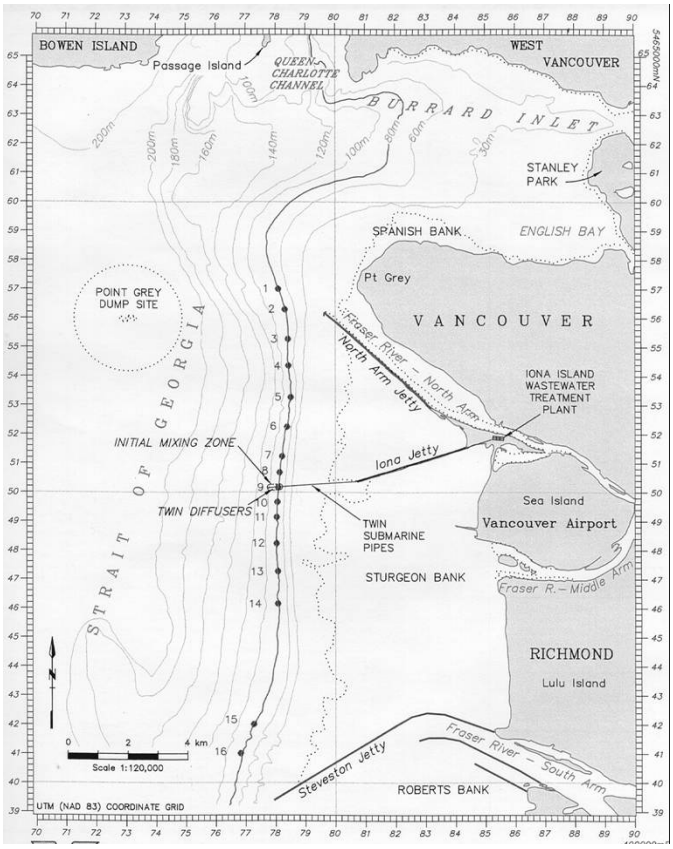

Figure 1. Station Locations for Revised Iona Monitoring Program along the 80 m depth contour

The gradient monitoring design for IONA has included sufficient samples to do near- and far-field comparisons of biotic factors with adequate statistical power, using simple 95% confidence intervals as criteria (based on Environment Canada EEM protocols for Pulp and Paper and Metal Mining: URL: http://www.on.ec.gc.ca/eem/pulppape-e.html). The biotic community in the Iona receiving environment is described in detail in Burd (2000, 2003), Bailey et al. 2003, and McPherson et al. 2001, 2002, 2004, 2005).

Sediment TOC levels are consistently low in the area, probably due to high inorganic input of particulate material from the south arm of the Fraser River. However, sediment AVS values show a temporally-consistent zone of sediment geochemical change related to the discharge, resulting from the production of hydrogen sulphide by bacteria living at the oxic/anoxic boundary in sediments, and the input of organic material. Mean 4-nonylphenol (4-NP) levels follow a pattern of distribution similar to AVS over time. 4-NP is considered an excellent indicator of sediment exposure to sewage discharge (Chapman and Paine 2000, Bailey et al. 2003).

The 2000 monitoring program showed clear sediment exposure and related biotic effects related to the discharge. Biotic effects in the Iona receiving environment are remarkably stable over time and appear to be related predominantly to organic enrichment rather than contaminants (see Burd 2003a). Figure 15 shows the zones of impact and reference or "background" conditions estimated using the method developed in Burd (2000, 2003). The stations are sorted into "most impacted", "less impacted", "background (or reference)" and "outside effects (confounded)", based on sediment chemistry and biotic patterns. The biotic and chemical exposure zones include the following categories, determined from detailed assessment of monitoring data from 2000 to 2003;

- Moderate Impoverishment (MI): 0-1km N
- Low Impoverishment (LI): 1-3 km N

- Biotically Enriched (BE): 3-4 km N, 0-1 km S
- Reference or background (R): 4-5 km N, 1-2 km S, 7-8 km S
- Outside Effects (OE): beyond outfall deposition

The zones match physical and chemical exposure patterns, are temporally stable, and statistically distinct in terms of overall community composition (Burd 2003, Mcpherson et al. 2004, 2005 draft).

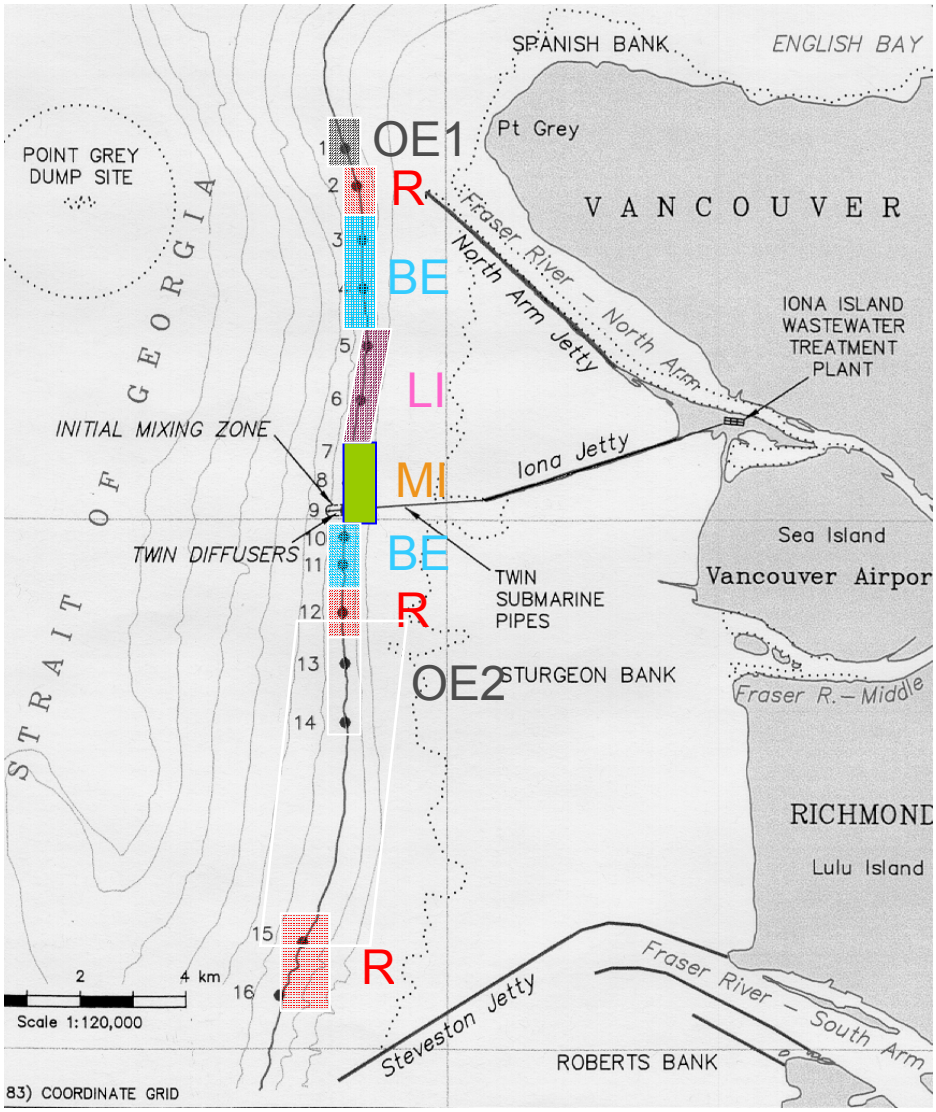

Figure 2. Derived "effect" zones for the Iona 80 m depth monitoring grid

OE1 = outside effect zone 1, OE2 = outside effect zone 2, R = reference zone, BE = biotically enriched zone, LI = low impoverishment zone, MI = moderate impoverishment zone

Cautions, Warnings and Triggers for Iona

The development of a benthic biotic trigger framework for Iona is dependent on selection of appropriate indicators and determination of reference ranges for those indicators. The types and spatial extent of effects of concern related to the

discharge must be identified and prioritised to allow selection of warning and trigger indicators related to benthic infauna. Effects of concern in this case are those outside what might occur naturally under various habitat conditions. For a detailed description of the ecological significance of these effects in the IONA and Lions Gate areas, and conditions for selection of indicators refer to GVRD (2004).

For example, issues used to aide in the selection of appropriate indicators for cautions, warnings and triggers can be described by addressing the following questions;

- Does the indicator shows statistically distinct patterns in different effect zones?
- Is the indicator pattern and magnitude consistent over time?
- Do confounding influences other than the outfall affect the indicator?
- Do reference ranges for the indicator show a reasonable within-site variability (sampling precision <20%)?
- Are reference ranges too close to zero to be useful?
- Are the indicators recognized as important biotic factors or used for guidelines in other jurisdictions?

This process, and the development of caution and trigger levels, depends on determination of reference ranges for candidate indicators. Reference levels for all indicators are estimated statistically, using confidence intervals or percentile ranges as shown in Figure 3 below. A cumulative frequency distribution of values for all samples within reference stations from 2001 to 2003 constitutes the historical reference ranges for comparison with all later sampling data. A similar approach can be used to determine historical ranges for the appropriate indicators within each of the identified effect zones for the development of warnings of change from historical conditions (see Fig. 3). Table 1 includes those factors selected as appropriate indicators, whether they are used as cautions, warnings or triggers, and the effect zones (see Fig. 2) in which they apply.

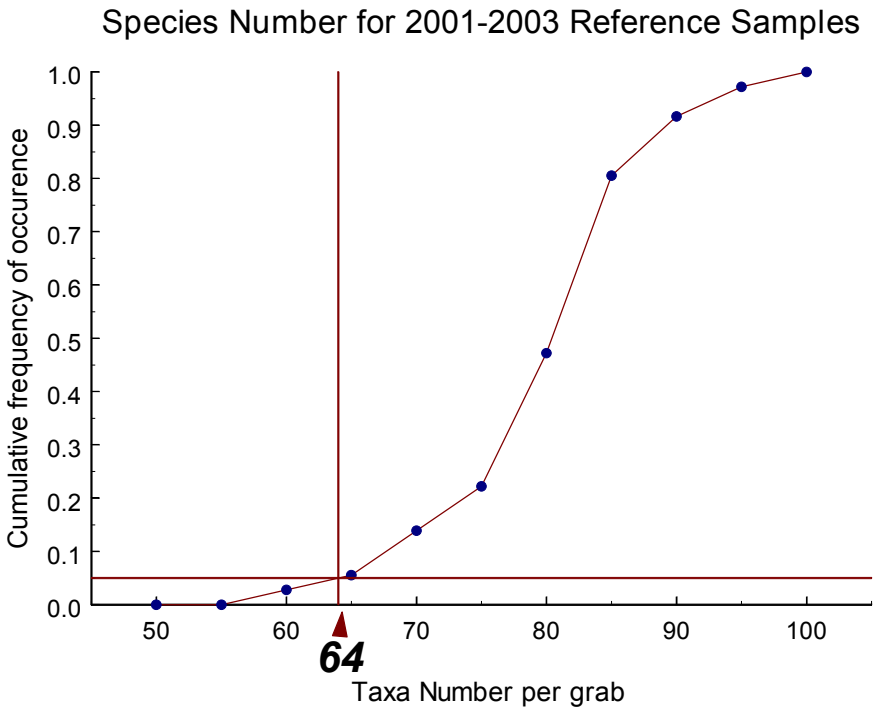

Figure 3. Example of calculation of reference limits for use in cautions and triggers using the Iona monitoring data from 2001 to 2003.

Table 1. Selected biotic, geochemical and contaminant indicators, Types and Zones of Application

	ZONE OF APPLICATION		
Indicator	**Caution**	**Warning**	**Trigger**
Echinoderm abundance	R	BE	
Crustacean abundance	R	BE	
%*Capitella capitata* complex	R	MI,LI,BE	MI,LI,BE
%*Heteromastus filobranchus*	R	MI,LI,BE	MI,LI,BE
%bivalves	R	MI,LI,BE	MI,LI,BE
Swartz Dominance Index	R		
Species richness	R	MI,LI,BE	MI,LI,BE
Bray-Curtis dissimilarity	R	BE	
Axinopsida serricata %adults with 0/1 stain on shell	R	BE	
Sediment fecal coliforms	R		
Sediment AVS*	R	MI,LI,BE	MI,LI,BE
Sediment 4-nonylphenol*	R	MI,LI,BE	MI,LI,BE

*note these are supporting indicators for biotic factors only: CCME (2002) has developed interim marine sediment quality guidelines for 4-NP of 1 mg/g for 1% TOC toxic equivalency units (TEU).

Biotic and Geochemical Cautions

Caution levels apply when any new reference samples fall outside +/-20% of existing reference ranges (this accounts for spatial heterogeneity based on acceptable sampling precision). Cautions are used for annual confirmation or re-calibration of Reference Ranges (95th percentile for R zone calculated over all previous years). Caution levels based on 95th percentile reference ranges +/- 20% (as appropriate). A change in the biotic indicator is assessed relative to the outfall by examining any concurrent changes in both a geochemical indicator of sediment enrichment (AVS) and a reliable sediment contaminant indicator of wastewater exposure (4-NP), to determine if the reference station has been affected by the outfall.

The consequence of reaching or exceeding caution levels is that certain responses are defined in keeping with the nature of the exceedence;

- *Caution Response 1*: Identification of cause (e.g., sampling or processing error, increased organic loading, natural region-wide phenomena, outside existing or new effects, etc.);
- *Caution Response 2:* If liquid waste discharge is source – risk assessment of temporal trend and determination of response need;
- *Caution Response 3:* Intensified sampling to confirm identification of cause and predict direction of trend and progression towards WQG or WQO and/or warning levels

Biotic and Geochemical Warnings

Warnings apply to identified affected zones in the Iona receiving environment. Warnings provide early indication of changes from existing condition in the zones affected by the discharge (impoverished or enriched; MI,LI,BE at Iona). The changes that result in Warnings are not known to be ecologically detrimental, but may ultimately lead to detrimental effects if the direction and rate of change continue. Warnings for impoverished zones at Iona (MI,LI) are based on estimated historical MI,LI range (95th percentile for data from 2001 to 2003 combined +/-20%); any 3 replicate samples outside this range in MI or LI zones for 2 sampling years exceeds the warning. Warnings for biotically enriched zones (BE) at Iona are based on estimated historical BE range (95th percentile for data from 2001 to 2003 +/-20%); any 3 replicate samples outside this range in BE or R zone for 2 sampling years.

The biotic warning levels must be reached concurrent with notable increases in AVS and 4-NP in order to relate the change to the outfall with reasonable confidence. A notable increase in AVS is an increase over 95th percentile +20% values for the relevant zone. A notable increase in 4-NP is an increase over 95th percentile +20% values for the relevant zone.

The consequence of reaching or exceeding warning levels is that certain responses are defined in keeping with the nature of the exceedence;

- *Warning Response 1*: Identification of cause (e.g., sampling or processing error, increased organic loading, natural region-wide phenomena, outside existing or new effects, etc.);
- *Warning Response 2*: If liquid waste discharge is source – risk assessment of temporal trend towards Water Quality Objectives or trigger status, potential effects on biotic communities and determination of best means to respond;
- *Warning Response 3*: Intensified sampling in receiving environment to confirm identification of cause and predict progression towards trigger status.

Biotic and Geochemical Triggers

A level for the indicator(s) has been reached which reflects probable ecological deterioration of concern in the receiving environment near-future, and requires immediate action to reverse the trend. The purpose of the trigger is to prevent deterioration of biotic condition past warning levels to levels of ecological damage.
Triggers for all zones are based on change from historical condition for that zone, past warning levels, to +/- 50% of reference ranges (based on 95th percentile *for a given year)* for any 3 replicate samples over 2 sampling years.

The biotic triggers must be reached concurrent with a notable increase in AVS and 4-NP. For AVS a notable change is 100% increase over 95th percentile +20% historical values for the relevant zone. For 4-NP a notable increase = up to 60% of the CCME Interim guidelines for expected Toxic Equivalent Units (TEU) for marine sediments at TOC=1% (CCME 2002).

The consequence of reaching or exceeding trigger levels is that certain responses are defined in keeping with the nature of the exceedence;

- *Trigger response 1*: Identification of cause (e.g., sampling or processing error, increased organic loading, natural region-wide phenomena, confounding effects, etc);
- *Trigger response 2*: Follow the trigger mechanism outlined in Figure 3 of the LWMP:
    - If liquid waste discharge is source, review mitigation options with the Environmental Monitoring Committee, sanction with the GVRD and present to the Province;
- *Trigger response 3*: Implement approved mitigation.

References

2WE Consulting 1999. Iona deep-sea outfall 1998 environmental monitoring program, post-discharge review, Report for Greater Vancouver Regional District by 2WE Associates Consulting Ltd., Victoria, B.C.

Bailey, H.C., C.A. McPherson, D. Hodgins, L. Fanning, M.D. Paine, B.J. Burd, V. Macdonald, G.G. Brooks, F. Chen, D. Brand and S. Raverty. 2003. Iona Deep-Sea Outfall, 2001 Environmental Monitoring Program. Final Report. Prepared for the Greater Vancouver Regional District (GVRD), Burnaby, BC by EVS Environment Consultants Ltd., North Vancouver, BC. May 2003. 344 pp. + appendices.

Burd, B.J. 2000. Ecological effects and indicators analysis for the IONA receiving environment. *In* Development of a receiving environment monitoring approach to liquid waste management: Progress workshop 2. *Edited by* GVRD. Burnaby, B.C. December 6, 2000. GVRD, pp. Chapter 5 - 48 pp.

Burd, B. J. 2002. Review of marine biotic, chemical and physical triggers, warning levels and indicators used in other jurisdictions. Consultant Report, Ecological Quality and Assessment Program: Greater Vancouver Regional District, Burnaby, BC.

Burd, B.J. 2003. Ecological significance of Iona 2000 – 2002 monitoring results for benthic infaunal communities. Final report to the Greater Vancouver Regional District, Burnaby, BC. June 5, 2003.

Chapman, P.M and Paine, M.D. 2000. Assessment of sediment chemistry in the IONA receiving environment. *In* Development of a receiving environment monitoring approach to liquid waste management: Progress Workshop 2. Vancouver, B.C. December 6, 2000. GVRD, pp. Ch. 2 2-1 to 2-73.

Hodgins, D.O., and Hodgins, S.L.M. 2000. A re-evaluation of Iona effluent solids deposition based on sediment grain size characteristics. *In* Development of a Receiving Environment Monitoring Approach to Liquid Waste Management. Progress Workshop 2 December 6, 2000. Support Material Part 2 of 3 Iona WWTP Receiving Environment. Draft Technical Report. GVRD, Burnaby, BC.

Gordon, K. 1997. Sedimentary tracers of sewage inputs to the southern Strait of Georgia. M.Sc., University of British Columbia, Vancouver, BC.

GVRD 2004. Greater Vancouver Regional District Cautions, Warnings and Triggers: A Process for protection of the receiving environment. Prep. For Ministry of Water, Land and Air Protection, January 2004.

McPherson, C.A., F. Landry, J. Wilcockson, B.J. Burd, S.E. Bertold, M.L. Fanning, M.C. Hamilton, G.G. Brooks, F. Chen and M. Gropen. 2001. Iona deep-sea outfall, 2000 environmental monitoring program. Prepared for the Greater Vancouver Regional District (GVRD), Burnaby, BC by EVS Environment Consultants Ltd., North Vancouver, BC and GVRD, Burnaby, BC. 156 pp.

McPherson, C.A., H.C. Bailey, P.M. Chapman, M.K. Lee, B.J. Burd, M.L. Fanning, M.D. Paine, M.C. Hamilton and F. Chen. 2003. Iona deep-sea outfall, 2002 environmental monitoring program: sediment effects survey. Prepared for the Greater Vancouver Regional District (GVRD), Burnaby, BC by EVS Environment Consultants Ltd., North Vancouver, BC. 223 pp. + appendices.

McPherson, C.A., P.M. Chapman, M.K. Lee, B.J. Burd, M.L. Fanning, M.C. Hamilton and F. Chen. 2004. Iona deep-sea outfall, 2003 environmental monitoring program: sediment effects survey. Draft Report. Prepared for the Greater Vancouver Regional District (GVRD), Burnaby, BC by EVS Environment Consultants Ltd., North Vancouver, BC. 262 pp. + appendices.

McPherson, C.A., P.M. Chapman, S. McKinnon, B.J. Burd, M.L. Fanning, J. Olson, M.C. Hamilton and F. Chen. 2004. Iona Deep-Sea Outfall, 2004 Environmental Monitoring Program: Sediment Effects Survey. Prepared for the Greater Vancouver Regional District (GVRD), Burnaby, BC by EVS Environment Consultants, North Vancouver, BC. 262 pp. + Appendices.